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Production of periphyton to enhance yield in polyculture ponds with carps and small indigenous species

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ABSTRACT

Although carp polyculture is well established throughout southern Asia, its overall efficiency in providing sufficient nutrients and financial profit remains variable. Site-specific adjustments are needed to improve efficiencies of polyculture under local circumstances. We evaluated variations of carp polyculture systems in two separate trials: one on a research station (on-station), and one in farmers' ponds (on-farm). The on-station experiment included four treatments: T_F (carp + 100% feed), T_{FS} (carp + SIS (small indigenous species) + 100% feed), T_{FSP} (carp + SIS + 50% feed + bamboo substrate) and T_{SP} (carp + SIS + bamboo substrate with no feed), each done with three replicates. Silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), rohu (*Labeo rohita*), *and* mrigal *(Cirrhinus mrigala)* were stocked at a ratio of 4:1:4:3:5:5 and a rate of 15,000 fish/ha. Additionally, 2 SIS, dedhuwa *(Esomus danricus)* and pothi *(Puntius sophore),* were stocked at 1:1 and a combined density of 50,000 fish/ha. Carps were fed daily at 5% of body weight (BW) for 60 days, then 2% BW for 150 days, using a supplemental feed composed of dough (mustard oil cake and rice bran (1:1)), or using grass (for grass carp). Total carp yield and FCR were highest in T_{FSP} ponds. Gross margin was also higher in treatments enhanced with periphyton (T_{FSP} and T_{SP}). Overall, T_{FSP} was determined the best on-station result, based on total production of fish and profit. The two treatments with the highest net fish yield, T_F and T_{FSP}, were introduced to 37 women farmers in Chitwan and Nawalparasi districts for on-farm trials. After 8 months of culture, total fish weight and gross margin were 24.0% and 51.2% higher, respectively, in T_{FSP} ponds than in T_F ponds. Reduced feed application with increased periphyton enhancement dramatically improved profit while maintaining fish yields similar to those of traditional polyculture systems with full feeding.

1. Introduction

Aquaculture is one of the fastest growing sectors in Nepal, with an annual growth rate of 9% (FAO, 2016). In recent years, the Nepalese government has recognized the potential of aquaculture for improving nutrition and economic opportunities of its citizens. However, despite recent efforts to encourage and promote local aquaculture practice, annual fish productivity from aquaculture remains low (3.89 $t\,ha^{-1}$), and citizens still lack sufficient access to fish, keeping consumption rates low as well (2.1 kg/person, annually; DoFD, 2013).

Polycultures incorporating carp species are among the most common fish culture systems in South and Southeast Asian countries. In India, Myanmar, Nepal, and Pakistan, carp culture alone represents more than 70% of all freshwater aquaculture production (FAO, 2016). However, due to lower demand and value for farmed carps in southern Asia, most polyculture systems use locally produced supplemental feeds rather than more expensive, nutritionally complete feeds (Mazid et al., 1997). Lower quality feeds often result in fish yields considerably lower than possible with better feeds, generating major concerns about under yielding (Iinuma et al., 1999). Improved feeding practices could lead to substantial improvements in polyculture production and subsequent increases in access to animal-source foods for people living in these regions (da Silva et al., 2006).

In commercial fish farming, feed alone accounts for approximately 60–80% of total operational costs (Bhujel, 2012; Price and Egna, 2014). As most small-scale farmers lack sufficient financial resources required

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to sustain their own aquaculture systems using only complete feed, developing low-cost alternatives is essential. Adding natural substrates, such as bamboo, to carp ponds can facilitate growth of periphyton, which serves as a natural food for carp, reduces reliance on commercial feed, and helps maintain farm production while keeping costs low. All species of carp commonly used in polyculture farms — Rohu (*Labeo rohita*), catla (*Catla catla*), and common carp (*Cyprinus carpio*) — are known to feed on periphyton when available (Rai and Yi, 2012). For each of these species, growth and production increased in ponds where substrate was added to facilitate periphyton colonization, compared to ponds where no substrate was added (Wahab et al., 1999; Azim et al., 2002; Alim et al., 2004; Rai et al., 2008).

Since combinations of cultured species and type of feed influence yield and costs, it is necessary to test the full combination of feed inputs, periphyton enhancement, and resulting production to understand the best system for commercial production (Diana, 2012a). Many species commonly used for freshwater polyculture (such as carp) feed at lower trophic levels and possess the ability to utilize natural feed (e.g., periphyton), supplemental feed, or a combination. Diana (2012b) and Borski et al. (2011) demonstrated that Nile tilapia (*Oreochromis niloticus*) had equivalent growth and yield when reared in ponds with full rations using nutritionally complete feed or ponds with only half rations. Consumption of natural food allowed tilapia to compensate for reduced feed inputs, while still allowing for optimal growth. Efficiently managed polyculture systems operate under this premise: inclusion of multiple species with the ability to utilize different food pathways within a single pond optimizes the uptake of available nutrients within a system (Milstein, 1992; Milstein et al., 2006). While a reduction in applied feed may not increase overall yield, it can make feed conversion and overall economic output higher and help reduce costs to small-scale farmers who rely on polyculture systems to satisfy daily nutritional needs and provide sustainable income (Azim et al., 2004).

Chronic malnutrition and micronutrient deficiency is a major problem in Nepal and other countries throughout Southeast Asia (UNICEF, 2012). With predicted continued shortfalls in animal-source foods, there is a critical need to develop environmentally sustainable and cost-effective methods for year-round food production that provide adequate nutrients through quality diets. Since 2008, the Institute of Agriculture and Animal Science (now Agriculture and Forestry University (AFU)) has promoted an innovative and environmentally sustainable household fish-production system (carp-SIS polyculture) to improve nutrition of poor women and children in the Terai (lowland) region of Nepal (Rai et al., 2012) and in regions of Bangladesh (Alim et al., 2004). The approach includes increased intake of nutrient-rich Small Indigenous Species (SIS). SIS are commonly eaten whole, and Vitamin A, calcium, zinc, and iron are much higher in the eyes, head, organs, and viscera of SIS, compared to the eaten components of other fishes (Roos et al., 2006). However, maintaining carp-SIS polyculture systems is more complicated, due to limited availability of SIS for stocking, and may not be feasible for many people in these regions.

The objectives of this study were: 1) to use on-station trials conducted at AFU to determine the best combination of carp, SIS, feed application rate, and periphyton enhancement choices to maximize net fish yield and profit in ponds; and 2) to test the best treatment combinations found on-station in objective 1 with farmers following similar protocols, but adapting them to suit real-world application (on-farm trials). We hypothesized that ponds with periphyton enhancement structures and reduced feeding (with a supplemental feed) would produce the best economic return, while still maintaining comparable yields to those of traditional carp polyculture systems, which include full feeding. We expected treatments that included fish species best able to utilize periphyton to require less feed, while still obtaining growth and harvest production in quantities similar to treatments where fish were provided only feed and no periphyton enhancement.

2. Methods

2.1. On-station trial

An on-station trial was conducted from 24 August 2014–28 March 2015 (210 days) at the Aquaculture Farm at AFU, Rampur, Chitwan, Nepal. Twelve earthen ponds were used, and treatment conditions for each pond were assigned using a completely randomized design (Egna and Boyd, 1997). There were 4 treatments, each with 3 replicates: T_F (carp + 100% feeding), T_{FS} (carp + SIS + 100% feeding), T_{FSP} (carp + SIS + 50% feeding + periphyton (bamboo substrate)), and T_{SP} (carp + SIS + periphyton with no feed). The average area of an experimental pond was 150.9 ± 4.1 m^2 (mean + SE), with individual ponds ranging in size from 117.7–168.5 m^2.

Prior to experimental trial, predatory fish were eradicated by applying bleaching powder to ponds at 250 kg/ha. Ponds were fertilized with urea after 15 days at 7 g/m^2 (2.16 g N/m^2) and diammonium phosphate (DAP) at 3.5 g/m^2 (0.63 g N and 0.71 g P/m^2). Bamboo substrate was installed for growth of periphyton in T_{FSP} and T_{SP} treatment ponds. Whole bamboo was cut into 1-m planks, split into 3–5-cm wide slats, and tied onto a rectangular bamboo mat using string. Sufficient space was left between slats to allow fish access to attached periphyton. Bamboo mats were suspended vertically in the water column with the top two edges tied to Styrofoam blocks serving as floats, and the bottom two edges tied to bricks serving as weights. Mats were constructed and installed so that two mats covered an area equivalent to 1% of total pond surface area.

Fish were stocked in each pond seven days after ponds were initially fertilized with urea and DAP. In all treatments, ponds were stocked with the traditional ratios and densities of carps, including silver carp (*Hypophthalmichthys molitrix*; 3000 fingerling/ha), bighead carp (*Aristichthys nobilis*; 750 fingerlings/ha), grass carp (*Ctenopharyngodon idella*; 2250 fingerlings/ha), common carp (3000 fingerlings/ha), rohu (3750 fingerlings/ha) and mrigal (*Cirrhinus mrigala*; 2250 fingerlings/ha). In treatment ponds containing SIS (T_{FS}, T_{FSP}, and T_{SP}), pothi (*Puntius sophore*) and dedhuwa (*Esomus danricus*) were stocked at 25,000 fingerlings/ha each. Grass carp were fed daily with locally available grass at 50% BW. Carp and SIS were given supplemental feed made of dough of mustard oil cake and rice bran (1:1), with 20–25% crude protein. In fed ponds (T_F, T_{FS}, and T_{FSP}), feed was provided every morning at 0900–1000 h. The full feeding rate in treatment ponds T_F and T_{FS} was 5% BW/day for the first two months, then 2% BW/day for the remainder of the experiment. Feeding rates in T_{FSP} ponds were half that of feeding rates in T_F and T_{FS} ponds, and no feed was used in T_{SP} ponds. Since part of the experiment was carried out during winter when metabolism and growth decline, winter feeding was done only when feed from the previous day was completely consumed, indicated by visual observation of rice bran and mustard oil cake remaining in the feeding tray. Fertilization with 7 g/m^2 of urea and 3.5 g/m^2 of DAP was done every two weeks to maintain periphyton growth. Fertilizers were soaked and dissolved in water a few hours prior to application for better efficiency (Diana, 2012b).

We measured temperature, dissolved oxygen (DO), and pH every two weeks at 0700–0800 h in water 10–20 cm deep. Water transparency, total alkalinity, total ammonia nitrogen, soluble reactive phosphorus, and chlorophyll-a were analyzed monthly at the AFU laboratory. Periphyton samples (1-cm^2 pieces) were taken randomly from bamboo substrate and analyzed following methods described in Azim et al. (2001a). Dry matter, ash content, and ash-free dry matter were estimated using methods from APHA (1980). Fish were sampled monthly to measure weight (g) and to better estimate the following month's feed application rate. At least 20% of all fish of each species were measured during each sampling. In March, we harvested fish by completely draining ponds using diesel pumps. All fish were counted and weighed to assess survival rate and production at final harvest. Daily weight gain (DWG) was calculated as the difference between